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A TRAINING COURSE IN FIRE BEHAVIOR

U.S. FOREST SERVICE
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CONTENTS

	Page
TO THE INSTRUCTOR	1
Demonstration Materials and Equipment	2
INTRODUCTION	3
PART I PHYSICAL PROCESSES	4
Ignition	4
Combustion	4
Heat Transfer	6
PART II EFFECT OF PHYSICAL FACTORS	8
Moisture Content of Fuel	9
Fuel Temperature	9
Wind	10
Slope	11
Fuel Types	12
PART III HOW THE FACTORS BEHAVE UNDER FIELD CONDITIONS	15
Fuel Moisture Content	15
Fuel Temperature	17
Wind	17
PART IV HOW FIRES RESPOND TO COMBINATIONS OF FACTORS	19

AGRICULTURE - FOREST SERVICE - SAN FRANCISCO

TO THE INSTRUCTOR

This course deals with the fundamental principles of fire and their specific application to the behavior of forest fires. It is not intended to be strictly technical, but is aimed at teaching the practical applications of technical knowledge of fire behavior. The course does not include all of the factors which are known to influence fire behavior, but does include those which are generally considered of primary importance. The principles and techniques of fire fighting are touched upon only to the extent necessary to illustrate applications of fire behavior. It is developed largely around methods of fire fighting that are concerned with removing the fuel, cooling down the fire, and cutting off the supply of oxygen.

The course may be considered rather elementary from the instructional viewpoint. It is designed to teach the fundamental principles to any group regardless of the knowledge level in other fields. However, once the student or trainee has a good knowledge of these basic principles, the level of use to which they are put may vary greatly; ranging from the use of the McLeod tool in scraping fire line to the calculation of probabilities on a major fire.

As methods and practices of forest fire fighting develop in line with the existing need for more precise fire control effort, it will be necessary to measure and evaluate the factors influencing fire behavior to a finer degree than is practiced at the present time. Even with our present methods of fire fighting, however, there is opportunity to better the methods used in solving those problems concerning which we make fire control decisions. We can do this by making an orderly analysis of the problem at hand and by making greater use of present, even though limited, knowledge of the basic principles of fire behavior. The primary purpose of this course is to provide information on some of the basic principles necessary to apply this approach to the practical job of suppressing fires.

The course is generally given in a warehouse or similar building in which electricity is available and an open fire may be used. On the following page is a list of materials and equipment needed for demonstration purposes. A short review of the text will help the instructor in setting the stage for their use. Note that paragraphs referring to demonstrations are indented.

Demonstration Materials and Equipment

Blackboard) Paper and easel
) or
Chalk, white and colored) Colored crayons

Eraser

Fire table*

Kitchen matches

One-lb. coffee can with small hole in cover

Small blow-torch or gas burner

Electric fan

Blacksmith tongs

Canvas, 4'x 4'

Fire Control Handbook, R-5

Hygrothermograph chart with record

Psychrometric tables, USWB

Fire Danger Rating Tables, slope class #1

Cigarettes

Fuels:

dry grass
" pine needles
" oak leaves
" twigs, sticks, branches, up to 1" in diam.
green twigs, needles, and leaves.
small cones.

*See Appendix A, following page 21.

A TRAINING COURSE IN FIRE BEHAVIOR*

INTRODUCTION

The odds are generally against the fire fighter unless he understands and takes advantage of every natural law which he can turn to his account and is prepared to guard against the inevitable adverse factors. In fact, success in fire fighting hinges to a very large extent upon one's ability to size up not only what the burning conditions are at a given time but also what they will be as the fire advances or as changes of weather may occur. Judgement in these matters must be based on an understanding of the basic principles governing the action of forest fires.

These principles are the basis for training in all phases of fire control. The knowledge of these principles will give the suppression crew member or novice a concept of fire behavior which will permit him to better understand the reasons for accepted practices in constructing fire line or any other methods of controlling a fire. The fireman will call on his knowledge of them when sizing up or preparing to attack a small fire. The lookout, by reason of his knowledge of the basic principles, can do a better job of reporting a fire and making an intelligent report of the progress of the fire. The fire boss can make an intelligent plan for the attack on a large fire if he has a good knowledge of these basic principles on which to base his calculations. The safety of men on fires is to a large extent dependent upon their own as well as the foreman's knowledge of how the fire is going to behave under certain circumstances.

*The material in this instruction guide was prepared from a training course developed and used by R. W. Asplund, Fire Control Officer, Trinity National Forest. The text was prepared by Alva G. Neuns, California Forest Experiment Station.

PART I

PHYSICAL PROCESSES INVOLVED IN BURNING

In order to fully understand the basic principles of fire control, we must know something of the processes of IGNITION, COMBUSTION and HEAT TRANSFER, all of which, when carried on more or less simultaneously, produce what is commonly called fire.

IGNITION

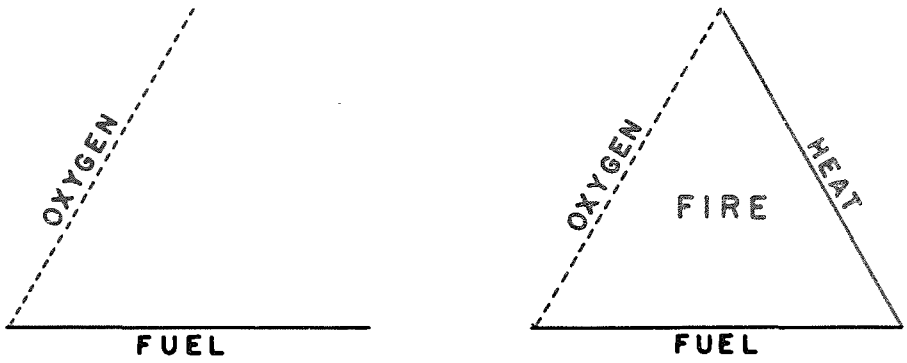
The beginning of rapid oxidation or burning is called ignition. It occurs when the temperature of a fuel is raised to what is called the kindling point. The kindling point for ordinary forest fuels is approximately 560°.

> Light a match and explain that heat by friction ignites the phosphorus of the match.
>
> Ignite dry pine needles and explain raising the temperature to the kindling point. Repeat, using heavier fuel (small dry twigs). Note that it takes longer with the same amount of heat. Discuss ignition time and inflammability. The length of time is an important factor to consider when calculating the chances of fires starting. Normally, the finer the fuel, the shorter the ignition time, all other factors being equal.

COMBUSTION

Whenever we have the temperature of combustible material raised to the kindling point in the presence of oxygen, we have what is known as combustion.

> Explain by means of the triangle with one side representing the fuel, another the oxygen and the third side the heat. Close the triangle and combustion results.



Perhaps a more technical explanation would be that when fuels are raised to a given temperature gases are produced which, combined with the oxygen of the air, will ignite and fire is the result. Considering the triangle in relation to forest fires, we will always have two sides present; namely, forest fuels and oxygen in the air. In order to have a fire we need only to supply the third side - heat. Of course, the most common source of heat is the match which is usually present when humans are around. Other sources of heat are: lightning, cigarettes, sparks from flues, and heat from the burning front after a fire is started.

> Place dry pine needles in a one-pound coffee can with a small hole in the lid. Heat fuel with a burner and ignite gas that is given off. Note only carbon is left in the can.
>
> Lay one end of a dry stick in the fire and observe ignition. Allow the fire to burn along the stick held horizontally. Explain that only the particles immediately adjacent to or in contact with the source of heat are raised to the kindling point. Explain gases given off mixed with the oxygen of the air and carbon remaining.
>
> Again refer to the triangle and the oxygen side. Normally, there is enough oxygen in the air to allow combustion to take place. Increase the supply of oxygen by forced draft and the fire will burn more rapidly. Remove the oxygen supply and the fire will go out.
>
> A small fire in needles on the fire table. Lay a canvas over the fuel and remove after a few seconds. Note that the fire has gone out as the supply of oxygen is cut off. It may again burst into flames after the canvas is removed if enough heat is still present.

Rate of combustion or the rate at which fuel is consumed varies with the fineness, compactness and distribution of the fuel.

> Light the open corner of a magazine and note that it burns slowly as the temperature is raised. Open the magazine--thus exposing the pages of the magazine to more oxygen causing them to burn more rapidly.
>
> Cover the fire table with oak leaves. Ignite the leaves and note the rate of spread. Stir the leaves and note increased rate of spread.

In field application this condition often occurs in the broad leaf types following the first fall rain.

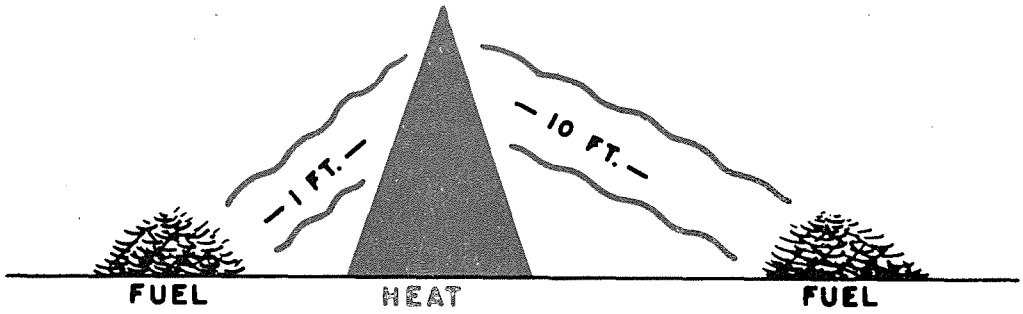
Also, the rate of combustion depends upon the way that the fuel particle receives heat from the flames generated by the fuel that is already burning. This introduces the third process mentioned above.

HEAT TRANSFER

Heat from a fire passes off largely by RADIATION and CONVECTION. Conduction is a third process of heat transfer but, since the conductivity of wood is very low, it is not considered worthy of consideration here.

Radiation

(Refer to a toaster.) Radiant heat decreases inversely with the square of the distance from the source. Material 10 feet away from a fire receives only 1-100 times as much heat as material only one foot away.



Light a small fire in pine needles and observe the spread as adjacent needles are affected by radiated heat. Increase the volume of fuel on a portion of the area and note the increased intensity. Use a slice of bread to show increased radiation.

Demonstrate lateral spread with fire burning in all directions. Remove the fuel from the immediate path of the radiated heat. Note that a wider gap is required in the heavier fuels. Explain that the heavier the fuel or the larger a fire becomes, the more difficult it is to control. Note: Another factor (drafts created by the fire itself) is involved which has the effect of slowing down the spread. It is merely mentioned here and will be explained later.

The most common method of fighting forest fires is based on the principle of producing a gap between the fire and the fuel.

> Place three or four dry sticks in a bed of coals and observe how they ignite and burn as they are affected by the radiated heat from each other. Remove the burning limbs from the fire and separate them beyond the reach of the radiated heat of each other. Observe that the fire dies down or goes out. Again place them close together and they will soon burn up.
>
> To illustrate a mop-up problem show on the blackboard a pile of logs burning on a hillside after the fire. Show them rolled out of their bed of coals and separated. Explain that the air temperature is cool, usually less than 100°, and the circulation of air has a cooling effect. Radiation is continuing and the fuel loses its heat.

One method of control of fires is by cooling down with water or earth.

> Demonstrate on the fire table and explain that the temperature of the earth beneath the surface of leaves is considerably below 100°, even in the summer.

Convection

Heat carried by the movement of hot masses of air which tend to rise is heat transferred by convection.

> Show by the flames and smoke from a small fire on the fire table.
>
> Hold a lighted match or small stick horizontally and note that the flame rising vertically has very little effect on the spread along the match, only the effect of radiated heat. Hold the match in a vertical position and note the effect. Heat by convection plus radiation increases the spread along the match stick.
>
> Repeat the demonstration, using a dry stick or limb (approximately 1" dia. and 18" long). Ignite one end of the stick, held horizontally. Now (by means of blacksmith tongs) hold the stick in a vertical position in the center of a bed of coals on the stick. Next, keep the stick in its vertical position but move it outside of the bed of coals and observe that it ceases to burn.

Show a snag by means of the blackboard or picture. As the snag burns, the coals drop to the ground and accumulate, sending a column of heated air back up to increase the fire in the snag. Remove the coals (source of heat) from the base of the snag and the fire will die down. Similarly, roll a log out of its bed of coals and turn it over so that the heat is above the fuel.

Show effect of heat rising by lighting a surface fire in needles. Hold a branch over the fire to show how the fire will spread to low brush or low hanging branches of a tree and note that the heat from the fire in the needles ignites the brush. On the blackboard show the fire spreading to tree crowns and explain that it is the effect of the heat rising from the fire below that raises the temperature of the crowns. Explain that fire may be prevented from reaching the crowns by removing the brush before it is ignited.

Refer to triangle once more. The first basic principle, then, of fire control is to make a break in the triangle.

Remove the fuel "leg".
Cut off supply of oxygen.
Reduce the temperature.

Remember the natural air temperature is normally below 100°. The natural tendency, then, is for temperatures of fuels exposed to the air to remain below the kindling point or drop below it unless heat is applied or circulation of cool air is cut off. The method by which these processes are carried out on fires and their practical application will be discussed later in the course.

PART II

EFFECTS OF PHYSICAL FACTORS

We have been discussing fire and the burning process without consideration of the influence of factors which are always present in varying degrees. The factors we will consider are Moisture Content of Fuel, Temperature, Air Movements, Slope and Types of Fuel.

These factors are discussed in the order listed. No attempt is made to place the importance of one over another since their relative value will vary according to location and condition. Each factor is discussed separately in order that the student may clearly understand and recognize the effect of a single factor. Since more than one factor is always involved, it becomes necessary to recognize and evaluate a combination of two or more factors. It is not practical in this course to cover all the combinations of factors that may be involved. However, if the fire fighter is able to recognize the effect of single factors, the evaluation of a combination of factors is greatly facilitated.

MOISTURE CONTENT OF FUEL

The moisture content of forest fuel affects or regulates the ignition time or degree of inflammability which in turn has a decided effect on the combustion rate or rate of spread. Heat applied to moist fuel is partly wasted in converting moisture to steam. Since the kindling point of forest fuel is about 560° and water is converted to steam at 212°, water on or near the surface of the fuel will be converted to steam before the kindling point is reached. Above 212° the heat is 100% effective. Drying inside the fuel continues while the fuel burns. Since it takes approximately one third as much heat to raise the temperature of wood one degree as it does water, the higher the moisture content of the fuel the more heat wasted and the slower both ignition and burning.

> Select two sticks approximately 1" in diameter, wet the surface of one and leave the other dry. Hold the sticks over a small fire or flame from a burner. Observe the moisture evaporating from the wet stick as steam; also ignition taking place in the dry stick first. Compare the length of time each stick must be exposed to the heat before ignition takes place.

If any firebrand such as a spark or cigarette lands on damp fuel, part of its heat will be expended in driving off moisture and the spark may go out before ignition takes place. If the firebrand is placed on dry fuels, less heat is required to raise the fuel to ignition temperature and ignition may take place more readily.

> Cover the fire table with a light covering of fuel and ignite across one end. Spray the fuel on half the width of the table. Compare the rate of spread when the fire reaches the wet fuel. If the fuel is wet only enough to slow up the rate of spread, you will note that the wet fuel will continue to burn slowly as the heat dries out the fuel. If the above demonstration is repeated, using varying amounts of moisture it will be noted that the more moisture applied the slower the rate of spread until finally the fuel will cease to burn.

FUEL TEMPERATURE

Fuel temperature has two direct effects on fire behavior. One effect is to change the net amount of heat required to bring fuel ahead of the flame front to the kindling point. Example: If the fuel temperature is 50° as a result of low air temperature, it will take more heat to raise the temperature to 560° than if the fuel temperature is 100°. Also, the air temperature regulates the rate of cooling of fuel by direct wind or in drafts. In other words, a certain amount of heat that is being delivered to the fuel by radiation and convection from the flame is taken away by the air moving past the fuel. A second effect of fuel temperature is to regulate the speed with which the fuel burns after it is once ignited. Warm fuels burn faster than cold.

Refer to FDR tables for slope class #1. Compare the value of a given fuel moisture and wind in the various temperature ranges.

WIND

The movement of air past a fire exerts a great influence on the rate of spread.

1. By augmenting the normal supply of oxygen; direct the wind from an electric fan into a small fire in pine needles on the fire table. Observe the increased rate of combustion which results from the increased supply of oxygen.

2. By changing the position of the flame; direct the wind from the fan in the direction the fire is spreading under existing conditions and observe the increased rate of spread. Note the angle of the flame in relation to the fuel. The radiated heat has a shorter distance to travel and is therefore more intense upon the fuel's surface.

   Show on the blackboard the angle of the flame in relation to the fuel.

3. By changing direction of the convection current; repeat the demonstration under number 2, using heavier fuel and stronger wind and note the convection heat as indicated by the smoke being directed through or close to the fuels ahead. This has the effect of preheating the fuels ahead of the radiated heat. Also, the cool air coming in from the rear has a cooling effect on fuels.

In field application this results in what is called the head or front and the rear of a fire. The spread at the rear of a fire is usually very slow and easy to work while the rate of spread at the head is fast. It is often times dangerous and sometimes impossible to work the head or the flank toward which the wind is blowing.

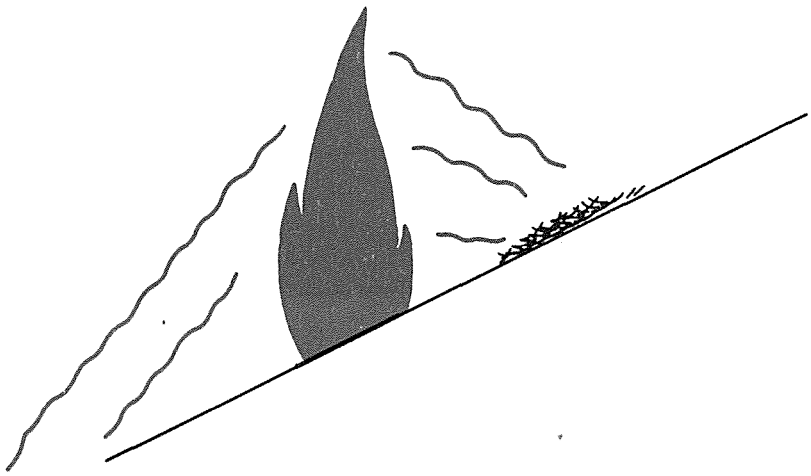
4. By carrying fire into the fuel ahead; direct a strong current of air from the fan into a fire burning in leaves or hot embers. Observe the spotting ahead which results in ignition in advance of the main fire.

In field application this sometimes presents a serious problem. You can usually tell where the sparks are lighting by observing the course of the smoke.

SLOPE

Fires normally travel up hill faster than down hill or on the level. The fuel on the upper slope is closer to the source of heat and also a larger surface is exposed to radiated heat. (Fuel sees more flame.)

Show on the blackboard the position of fuel in relation to the flame.



Heat is also carried to the fuel upslope by convection.

On raised end of table covered with needles, start a fire at the top edge. Observe how slowly it burns down hill. Flames and radiated heat directed above and away from fuel. Repeat and light the fire at the bottom edge of the slope. Observe the rapid spread up the slope. Note that the fuel is closer to the flame. Also, the draft created by the fire tends to follow the slope carrying the heat and flames toward the fuel which has the effect of preheating the fuel well in advance of the fire itself. Observe that the fire burns up the slope wedge shape, as a result of the concentration of the draft near

the center of the fire. Note also, that the drafts are into the fire on both flanks. In application, this permits working the flanks even of a fast running fire.

Show on the blackboard how the shape of the front will vary according to the steepness of the slope and the volume of fuel.

On very steep slopes there is also the effect of rolling material on the spread of fires.

Demonstrate by covering the raised end of the fire table with a covering of needles and place a few small cones on the slope. Light the fuel at the top of the slope and observe that the cones roll down as the fuel is burned away, causing an increased rate of spread downhill. Note that the steepness of the slope has a decided effect on the danger of rolling; also some fuels are more apt to roll than others. Burning logs and hot coals are examples of rolling material.

Show on the blackboard the technique of preventing burning material from rolling down hill, i.e., trenching the position of burning material.

FUEL TYPES

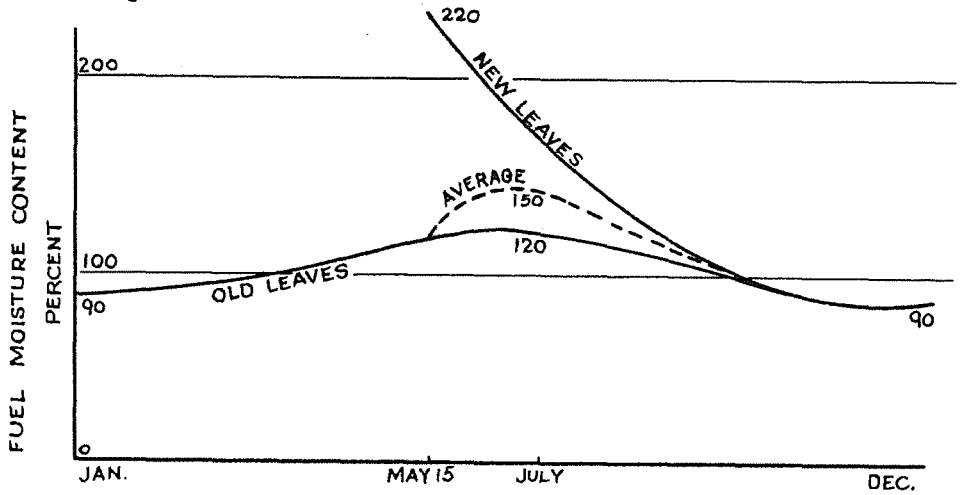
The effect of cover on fire behavior is governed by its fuel characteristics which have a direct bearing on rate of ignition and combustion and the process of heat transfer. In addition, cover has indirect effects through its reaction to relative humidity, wind and temperature. The following are characteristics of fuel to be considered: Volume, fineness, compactness, arrangement, moisture content and dead to green ratio. Some of their effects on fire are illustrated as follows:

Fine fuels such as grass and needles, as explained under "Ignition", ignite more quickly than coarser twigs and limbs found in the brush type because of the size of the fuel particle. In addition, there is the close relationship between fuel moisture and relative humidity in lighter fuels.

In application, a fire may be burning in an annual grass type and spreading very rapidly with a fuel moisture of 4%. If the relative humidity increases, the moisture content of the fuel will increase almost immediately and the rate of spread will be directly affected. If a fire is burning in a mixed chaparral type under similar conditions, a rise in R.H. will not be reflected as quickly because the fuels will not absorb moisture as rapidly.

The moisture content of green foliage in the mixed chaparral will vary with the season of the year. During the winter and early spring before the new growth starts, the total moisture content of the fuel is low. The moisture content increases with the new growth and decreases again in the fall. Serious fires in mixed chaparral do not occur during the period of new growth except under the most critical weather conditions.

Illustrate on the blackboard the relationship of new growth and old growth to total moisture content of chaparral.



Dead to green ratio in mixed chaparral is another characteristic to consider. Fires in this type will spread less rapidly under given conditions if the brush is young and thrifty with a small amount of dead twigs. As the brush gets older, the amount of dead twigs increases and the rate of combustion will increase considerably.

The volume of fuel, especially on the ground, has important effects on behavior. A fire in a dense woodland type will continue to burn hot with a rapid rate of spread under given conditions if there is enough fuel on the ground under the canopy to ignite and sustain combustion in the crowns. If the volume of fuel on the ground is light, the crowns normally will not burn. Cover types also have a great effect on resistance to control; i.e., volume of work, volume of fuel that will hold fire, and special hazards such as snags that require special treatment.

The density and arrangement of cover also modify air movement or wind near the ground.

Illustrate on blackboard wind velocities in various fuel types in relation to the 20-foot velocity. Wind of a given velocity will have less effect on a fire in a moderately dense stand of mature timber than in grass or brush.

Certain fuel types, such as rotten wood and duff, are very susceptible to spot fires. These fuels become very dry during periods of low humidity and have a very definite effect on the spread of fires.

It is necessary for the fire fighter to become thoroughly familiar with the various fuel types within his area and to study their reactions to the factors involved which in turn influence fire behavior.

The following are common fuel types in Region 5 which have their own peculiar characteristics which influence fire behavior:

1. Annual grass (green, curing, dead); highly sensitive to changes in R.H. when dead. Burns with a minimum volume of heat.

2. Sage brush - highly sensitive to changes in R.H. Sparce fuel. Will not sustain a rate of spread except with strong wind.

3. Mixed brush - chaparral, subject to wide range in amount of fuel moisture as influenced by seasons. Large volume of fuel produces large volume of heat. Large leaves of certain species cause "spotting".

4. Chamise - sensitive to changes in R.H. Not enough volume of heat to sustain rate of spread when R.H. rises and wind decreases.

5. Open woodland - light ground cover (annual grass, leaves). Not enough fuel to cause fire to burn in crowns.

6. Dense woodland - heavy volume of fuel, especially crown.

7. Ponderosa pine - heavy volume of fuel both surface and crown. Not so sensitive to changes in R.H. Heavier fuels retain fuel moisture until mid-summer. Once they become dry they do not absorb moisture readily and short periods of high R.H. have very little effect.

8. Douglas fir - generally higher fuel moisture. Less ground cover than ponderosa pine.

9. Mixed conifer - heavy volume of fuel but generally higher fuel moisture, depending on percentage of fir.

10. Fir - generally high fuel moisture.

11. Desert - very sparce cover.

PART III

HOW THE FACTORS BEHAVE UNDER FIELD CONDITIONS

It is essential that one know how each of the physical factors above affect fire behavior. In order to make use of this knowledge, however, one must also know how to recognize the status of each one at any time and then predict what the status will be as the fire progresses. We need to know what makes each factor change. We need to know how to recognize the changes as and before they occur, if we are going to plan ahead of a fire. Some of the things we need to know about the factors follow:

FUEL MOISTURE CONTENT

Our common dead fuels such as litter, limbwood, logs, etc., are hygroscopic. This means that they absorb moisture from the air or give it up to the air, according to the amount of moisture in the fuel, the amount of moisture in the air (relative humidity) and the air temperature.

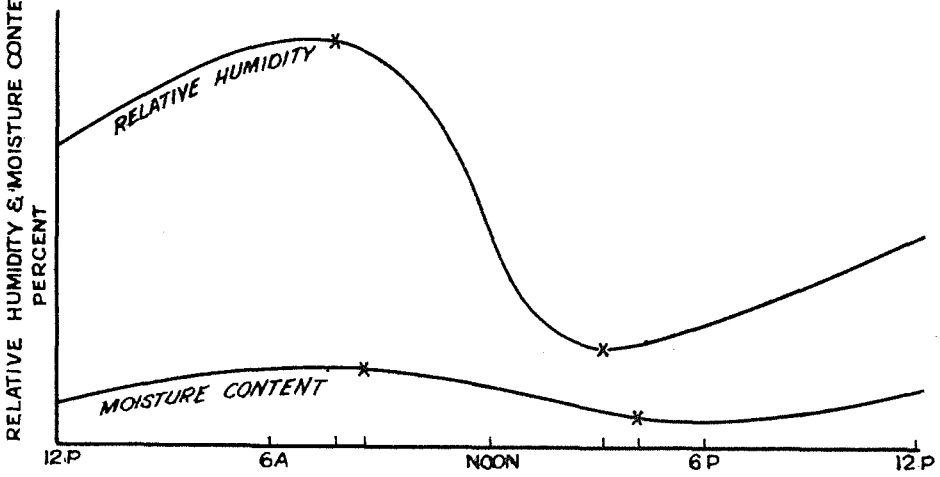
If left in an atmosphere of constant temperature and relative humidity long enough, fuels will take up or give off moisture until the moisture content reaches a point that is in equilibrium or balance with the constant relative humidity and temperature. The natural tendency for fuel and air to reach this equilibrium results in almost a constant interchange. When the fuel moisture is below the equilibrium, the fuel is absorbing moisture from the air. When the fuel moisture is above equilibrium, the air is absorbing moisture from fuels. The rapidity with which this interchange takes place depends upon the size of the fuel, the amount of moisture in the fuel, and the air temperature and humidity. Moss and dry grass respond within a few minutes, while heavier fuel responds very slowly.

Since only the surface of a log or other heavy fuel which is saturated with moisture is exposed to the air, the interchange is very slow except on the immediate surface. Before the log reaches equilibrium, all the moisture interchange must pass through the surface. The greater the difference between the moisture content of the fuel and the relative humidity of the air, the greater the evaporation. Also, the longer the log is exposed to air of low relative humidity, the drier it becomes.

Relative humidity is therefore an important weather factor that should be well understood by all fire men. It is always changing. If it is to have value as a fire indicator, it must be kept in mind all the time.

> Show a typical hygrothermograph chart record to demonstrate the kinds of changes in humidity that take place during a summer day.

Show on the blackboard how moisture content of fine fuels changes with humidity during 24 hours.



Relative humidity is easy to measure in the field and is therefore a convenient guide to fuel moisture conditions in the following cases:

1. Since fires normally spread in the lighter surface fuels, there is a direct relationship between relative humidity and the rate of spread of fires in such fuels as grass and needles.

2. Fires spread less rapidly at normally high night humidities and are usually more easily controlled.

3. Long periods of low R. H. result in critical burning conditions due to the fact that the heavier fuels are affected (low fuel moisture).

4. Low R. H. in the spring or early summer are not as serious as in late summer or fall.

5. As the dry season of the year progresses and daily periods of low humidity become longer, fuel moisture becomes correspondingly lower and fires burn with greater intensity and are more difficult to control.

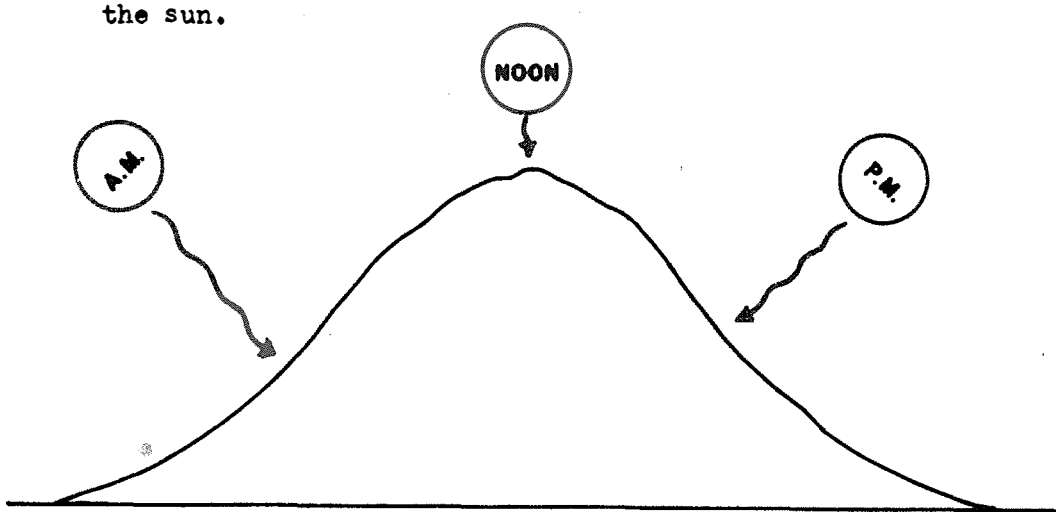
6. As the relative humidity rises, the fuel moisture increases until it reaches a point where fires will cease to spread. This point of relative humidity varies with the fuel type and must be determined locally by the fire fighter. As an example, it can be safely said that a fire in annual grass will do very little spreading when the R.H. raises to 40% unless there is a wind.

7. Backfiring is an effective means of controlling a fire, but to be effective the job must be done while the fuels will still burn. Therefore, if a backfiring job is indicated, it is necessary to plan the work so that the firing will be accomplished during proper fuel moisture conditions.

FUEL TEMPERATURE

Fuel temperature changes with the weather and with time of day. Normally, fuel temperature follows air temperature. But fuels exposed to direct rays of the sun are frequently heated to temperatures considerably above air temperatures. The amount of heating by exposure to the sun differs with time of day, direction and steepness of slopes, and wind velocity. Surface fuel temperatures over 150° occur often in areas sheltered from the wind. Highest temperatures occur when direction of the sun is perpendicular to the ground surface.

Show on blackboard how surface fuel temperatures are affected by topography and height and direction of the sun.



WIND

Because of the effect of wind on fire behavior it is essential that the firefighter become familiar with local wind movements. There are the normal prevailing winds typical of every locality. These winds occur with a fair degree of regularity with little diurnal variation except as they are affected by topography or convection winds.

Show on the blackboard the effect of topography on prevailing wind.

In most of the mountainous regions there is generally a local breeze up-canyon during the day and down at night. This is explained by the fact that warm air rises and as the sun warms the air near the surface of the earth it tends to rise and cool air flows in to replace it. At night the opposite is true and as the air cools the draft is usually down-slope. During the day time the air is expanding as it rises and the convection layer increases in depth. At night the air is contracting and the depth of the air in down-drafts decreases to a few feet on slopes.

Often times large fires can be controlled with comparative ease by taking advantage of this normal wind shift.

Show on the blackboard a fire burning with the wind on the level or a broad slope with the head and "hot" flank burning too hot to control. Control the cool side and the rear before the wind shifts. Control the hot flank after the wind shifts.

Drafts or air currents set in motion by the fire itself have a decided effect on fire behavior. These drafts are governed by the fact that warm air is lighter than cold.

Light a small fire on the fire table. Observe the natural tendency is for the column of hot burned air to rise. Hold a lighted cigarette or other smoking material near the base and observe the draft toward the base of the fire. Note that this is a result of cold air flowing in to replace the warm air. This has the direct effect of increasing combustion by increasing the supply of oxygen. Apply additional fuel, increasing the intensity of the heat and observe the increase in the air movement.

In large fires or fires with a heavy concentration of fuel, such as a burning building, the draft becomes so strong that shingles or large pieces of burning fuel are carried high into the air. Often times a strong wind results in the vicinity of the fire when a few miles distant there is no breeze.

At times when very heavy concentrations of fuel are present, the draft toward the center of the fire becomes so strong as to offset the effect of prevailing wind or other factors and results in a decrease in the rate of spread.

In practical application it is often possible to take advantage of convection currents in backfiring to stop the spread of a fast running fire, especially in heavy fuels.

A fire burning the width of the table in needles. Observe that there is a draft toward the head and flanks of the fire. From a narrow line start a backfire and observe the increased spread as the backfire approaches the main fire. In application, the heat and draft created by the main fire can be observed by movement of leaves or twigs of trees and by smoke columns. On a large fire the draft is usually stronger on one side of the fire, either on account of a supplementing breeze mentioned above or freer access as a result of the fire burning on a slope, which is the next factor discussed.

Light a fire in a light covering of needles on the fire table. Increase the volume of fuel. Observe that the rate of spread increases momentarily and again decreases as the heat is generated and a draft is created. This same condition results in a fire burning with a wide head instead of tending to burn wedge shape. Demonstrate on the table the difference in the width of the head under heavy fuel conditions. Use the fan to increase the rate of spread in one direction.

Fires in a heavy slash do not usually spread very rapidly unless there is a strong wind blowing. Even though the heat is very intense, there is usually time to construct a line or bring up equipment to cool down the fire.

PART IV

HOW FIRES RESPOND TO COMBINATIONS OF FACTORS

We have been thinking of or discussing the effect of each factor more or less independently. It should again be emphasized here that there is always more than one factor involved and it is necessary for the fire fighter to recognize and evaluate the combination of factors present. However, there is often one or two controlling factors in every problem which, if properly evaluated, will be the key to the solution.

A frequent combination of important factors is that of slope and wind. They have similar effects on fire spread. When wind blows up-slope, their effects combine. When it is other than up-slope, fire will follow a compromise between the two forces.

> Demonstrate the effect of a combination of slope and wind when the wind is across or is at an angle to the slope. Light a fire across the lower end of the raised portion of the table. Direct the fan across the table. Observe that the fire travels up the slope at an angle. Note that the wind counteracts the effect of slope or visa versa. In application, there is usually some up-canyon wind which causes the fire to burn up-slope at an angle. The angle will vary according to the characteristics of the convection column on the slope and the velocity of the wind. Also, a gentle to moderate slope will have little effect on a fire traveling with a strong wind.
>
> Show on blackboard that as a fire approaches the top of a ridge it is affected by the natural up-draft on the opposite slope. This, together with the inrush of cool air displacing the mass of warm air rising at the head of the fire, results in a definite slowing up in the rate of spread. Also, the up-draft from the opposite slope counteracts to a certain degree the draft created by the fire and results in the smoke and burning embers being carried back over the fire area. In practical application this permits construction of a line a short distance over the ridge from the fire which can be fired and held. The steepness of the slope opposite the fire, the type of cover on the slope, whether it is a north or south exposure and the depth of the canyon all have a bearing on wind or draft conditions along ridge tops.

Example: If the opposite slope has a north exposure and the cover is Douglas fir, the natural up-draft will be less compared to a slope with a west or south exposure and brush cover.

Examples of the Effect of Change of a Single Factor

1. A fire burning in grass, woodland or chamise type with a light to gentle wind. A rise in fuel moisture alone would result in a change in the character of the fire.

2. A fire burning on a level or moderate slope. If it reaches a steep slope the rate of spread will increase, even though all other factors and conditions remain the same.

3. A fire burning in heavy mixed chaparral type under given conditions. If the fuel type changes to woodland or an open stand of mixed conifer, the character of the fire will immediately change.

Examples of Behavior and Control of Fires Which Involve One or More Factors

1. A small fire spreading in pine needles on a gentle slope - largely the effect of radiated heat with a slight effect of slope. Control is accomplished by scraping a line around the fire; narrow on the flanks and rear, wider at the head - demonstrates the principle of removing fuel from radiated heat. Note that the line is wider than necessary.

2. A small fire in heavy fuel (brush or reproduction). Control is accomplished by cooling down with dirt and constructing a narrow line.

3. A small fire burning on a steep slope - (50%) with rolling material (cones and small logs). Control is accomplished by constructing a narrow line at the base or rear of the fire and trenching. Depth of trench depends on the steepness of the slope and the amount of rolling material.

4. A fire burning on the level or gentle slope with a strong wind. Note that the fire spreads very slowly against the wind but is very hot and spreading rapidly with the wind. Control is accomplished by working the cool flank and rear. With a shift in the wind to down-canyon at night, the hot flank and head cool down and are easily controlled.

5. Fire burning in a mixed grass and chamise cover on a steep slope with no wind. Fire is spreading very rapidly up the slope with no wind. Fire is spreading very rapidly up the slope

with intermittent runs along the flank which make direct attack dangerous and impractical. Control is accomplished by waiting for the predicted rise in R.H. which causes the fire to stop spreading and permits cold trailing or working close to the fire edge.

6. A large fire spreading rapidly with the wind on a gentle slope. Too hot to permit direct attack at the head. Control is accomplished by constructing line far enough in advance of the head of the fire to allow time to complete line construction and backfire. Backfiring should be timed to take advantage of the back draft created by the main fire. The line is constructed at an angle to the head of the fire so that the fire will not reach the line across the entire front at the same time.

7. A large fire burning on a steep slope in mixed cover types (heavy mixed brush, annual grass and dense woodland). Control to be accomplished by indirect method with a considerable amount of "backfiring" or "burning out", necessary plan must provide for the burning to be completed during the period when a satisfactory burn can be obtained. (Consideration of fuel types and their effect on rate of spread.)

APPENDIX A

THE FIRE TABLE

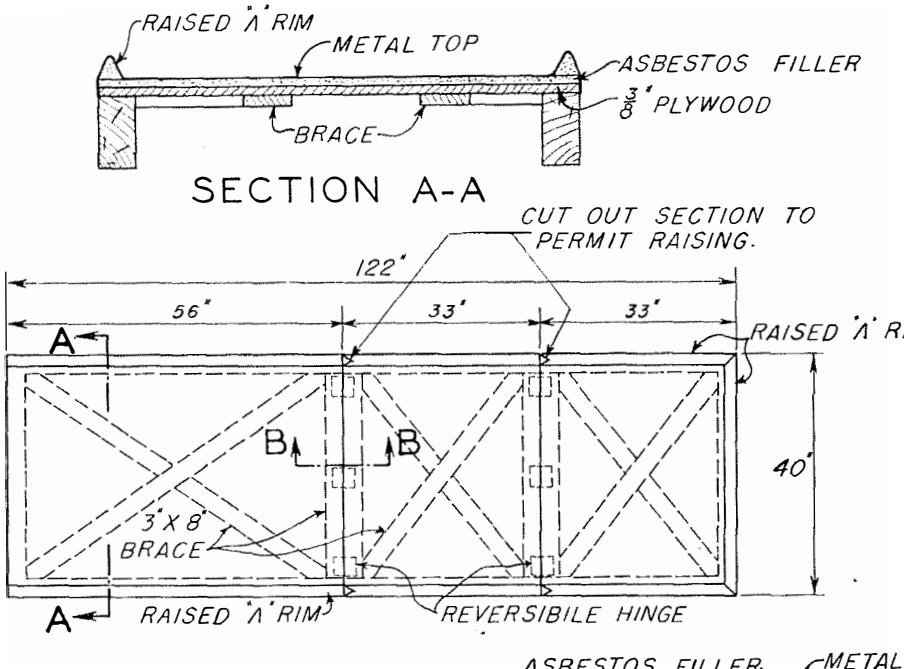
As an instruction aid, light fuels are spread on top of a simply constructed table and ignited to illustrate the spread of fire under various simulated conditions of fuel, wind, fuel moisture and slope.

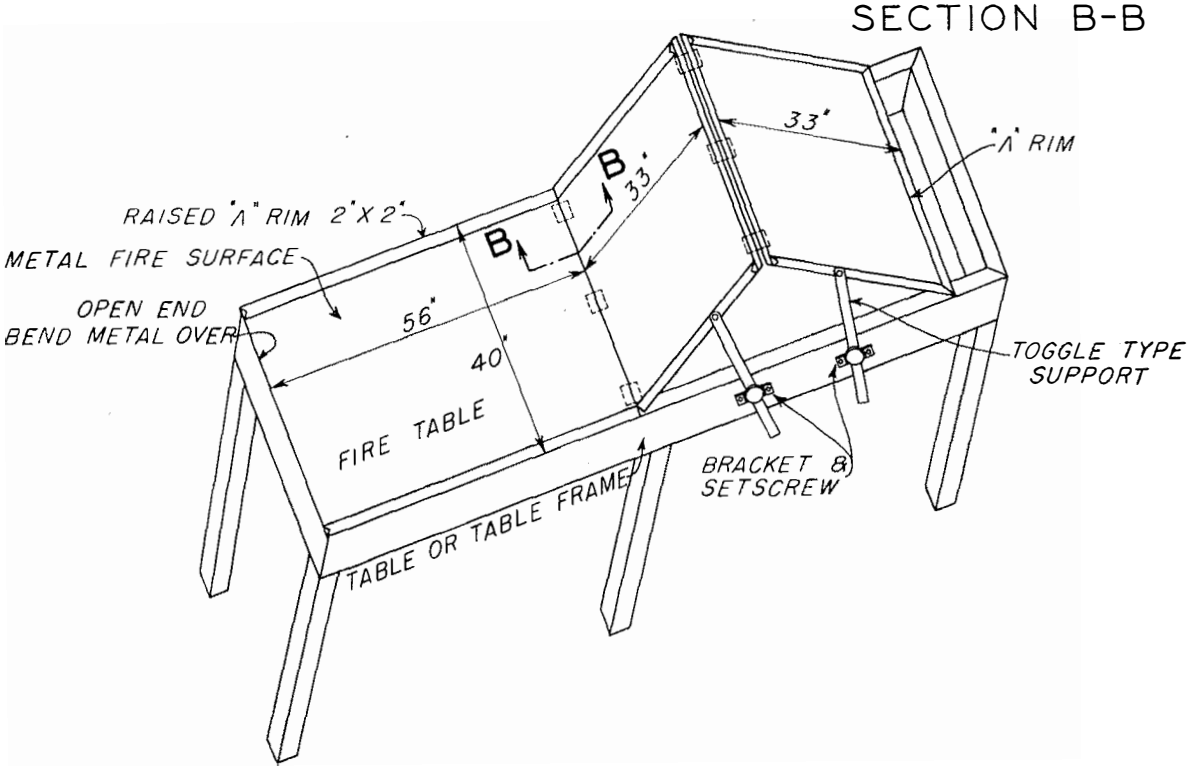
A small fan such as a defroster fan connected to a storage battery simulates wind. A fly spray gun will serve to supply the moisture to vary fuel moisture. The adjustable portion of the table (see the attached diagram) permits the slope to be changed as desired.

Pine needles, grass or hardwood leaves may be used to represent light fuels, with small limbs, twigs and pine cones serving as heavier types of fuel. (Fuels must be thoroughly dry. The demonstration should be held in a sheltered spot, free from the effects of local wind.)

The construction of the table is shown in the attached drawing. The table is approximately 10 feet long by 3-1/2 feet wide and consists of 3 sections. The long section is approximately 56 inches long and each of the others 33 inches long. The table top is a piece of sheet metal with plywood backing, protected from the heat by asbestos fiber.

The metal is shaped in an inverted "V" rim on the edges to keep the fire from falling off. One end of the metal on the long section is turned down to permit easy removal of the ashes. The hinged ends of the short sections are beveled and reversible hinges used to allow raising or lowering to the desired slope; also the metal rim is cut out at this joint to permit raising the table sections without binding. The hinged sections are covered with 2-inch chicken wire on top of the tin to prevent the fuel from sliding when the hinged sections are raised.


RAISED "Λ" RIM
METAL TOP
ASBESTOS FILLER
3/4" PLYWOOD
BRACE
SECTION A-A
CUT OUT SECTION TO PERMIT RAISING.
122"
56"
33"
33"
RAISED "Λ" RIM
A
B
B
40"
3"X 8" BRACE
A
RAISED "Λ" RIM
REVERSIBILE HINGE
ASBESTOS FILLER
METAL TOP
3/4" PLYWOOD
HINGE
BRACE
SECTION B-B


33"
"Λ" RIM
B
33"
RAISED "Λ" RIM 2"X 2"
B
METAL FIRE SURFACE
OPEN END
BEND METAL OVER
56"
40"
FIRE TABLE
TOGGLE TYPE SUPPORT
BRACKET & SETSCREW
TABLE OR TABLE FRAME

FIRE TABLE